

## Modelling residential smart energy schemes

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## Outline





- 2 Stochastic HYPE
- O Prototype model
- 4 Results
- 5 Extensions
- 6 Conclusions

#### QUANTICOL

Quantitative modelling of collective adaptive systems (CAS)

- Scalable, population-based quantitative dynamic modelling
- Abstraction and fluid and mean-field approximations
- Formal language for description of CAS
- Modelling to reason about existing and potential systems
- Case studies from smart transport and smart grids
- Spatial aspects are crucial to case studies
- Investigation of existing quantified spatial approaches
- Development of appropriate modelling techniques
- Design workflow for quantitative modelling of CAS

quantic

#### Residential smart grids

Local generation of renewable energy plus grid supply

- Collective: multiple households with various characteristics together with communication between them
- Adaptive: responds to information about prices and unused renewable energy, policies are necessary
- Prototype model to explore and understand features of scenario
- Use of an expressive formalism (stochastic HYPE) with an existing simulation tool (SimHyA)
- Spatial aspects in the case of multiple neighbourhoods
- Application of spatial moment closure techniques

quantic



#### Stochastic hybrid process algebra

Continuous, stochastic and instantaneous behaviour

- Process algebra: small, elegant, formal language to describe concurrent behaviour with mathematical semantics
- Stochastic HYPE is very expressive, simulation for analysis
- Flows of energy are represented as continuous behaviour
- Availability of renewable energy and absence of vehicle can be expressed by stochastic durations
- Changes of policy and changes in energy flows can be captured through conditions for instantaneous events



- neighbourhood: four houses in a circle linked to neighbours
- household: wind turbine, plug-in hybrid electric vehicle (PHEV)
- electricity has three prices: peak, mid-peak, off-peak
- battery charging policy
  - if wind turbine generating then charge PHEV battery
  - if battery below threshold then charge from grid
  - if battery above threshold and not peak then charge from grid
- energy sharing policy
  - if wind turbine generating and battery is full or absent then offer energy to connected neighbour



- weekday behaviour only
- wind: exponential distributions for presence and absence of sufficient wind to generate energy to match UK average
- departure of PHEV: exponentially distributed time after 7am
- return of PHEV: exponentially distributed time after 4pm
- distance travelled: exponential distribution with average 40 km
- battery parameters: from actual vehicle
- wind turbine parameters: from actual turbine



- no generation of energy by wind
  - wind generation without sharing
  - wind generation with sharing
- efficiency measures
  - cost efficiency: ratio of savings to costs without renewables
  - energy efficiency: ratio of renewable energy to all energy
  - wind efficiency: ration of wind used to wind available
- results with battery threshold of 4 kWh for initial charge

	no wind	no sharing	sharing
cost	$\pounds 106.51$	£64.19	£47.67
cost efficiency		40%	55%
energy efficiency		30%	38%
wind efficiency		48%	62%

quantico

#### Results: energy from grid



(average of 50 simulations of a 20-day period)

quanticol

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### Results: cost of energy from grid



(average of 50 simulations of a 20-day period)

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#### Results: efficiency





(average of 50 simulations of a 20-day period)





- addition of appliances to enable better use of renewables in household
- addition of household battery to enable better storage of renewables in household
- addition of photovoltaic panels to use solar energy
- limitation about number of batteries being charged at peak periods
- neighbourhood wind turbine rather than household wind turbines
- possibility of returning extra power to grid
- policies: first-come, first served or something else?

## Extensions (continued)



- more formal treatment of various energy sources and storage
  - HR household renewables
  - ND household connection to neighbourhood distribution point
  - GR neighbourhood connection to national grid
  - FS household fixed storage
  - MS household mobile storage
  - AP household appliances
  - NR neighbourhood renewables
  - NS neighbourhood fixed storage
  - CN connections to other neighbourhoods

## Extensions (continued)



quantitative description of energy flows

	HR	ND	GR	FS	MS	AP
HR	Х	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]
ND	Х	Х	[0,1]	[0,1]	[0,1]	[0,1]
GR	Х	Х	Х	[0,1]	[0,1]	$\{0,1\}$
FS	Х	Х	Х	Х	[0,1]	[0,1]
MS	Х	Х	Х	Х	Х	[0,1]
AP	Х	Х	Х	Х	Х	Х

separation of concerns: physical events versus policiesscalable modelling: suburb of many neighbourhoods





- Prototype model of residential smart energy scheme
- Simulation to explore scenario and compare policies
- Going forward with extensions to the model
- Scalable model of many neighbourhoods with spatial variation
- Fluid, hybrid and system-of-systems techniques



# Thank you